GEOTHERMAL ENERGY

by

Benjamin J. Slane

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Thesis Advisor

Department of Geology
and Mineralogy

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INTRODUCTION

In principle, the term "geothermal energy" includes all of the heat contained in about 260 billion cubic miles of rocks and metallic alloys at or near their melting temperatures, constituting the entire volume of the earth, except for a relatively thin, comparatively cool crust on its outer surface.[1] In practice, the potentially useful part of this enormous energy supply is represented by that small fraction of the earth's volume in which crustal rocks, sediments, volcanic deposits, water, and steam and other gases at usefully high temperatures are accessible from the earth's surface and from which it may somehow be possible to extract usable heat economically.

In a few fortunate places, nature delivers geothermal energy to the earth's surface in the form of steam or of superheated water that flashes to steam, and this natural steam can be used directly to generate electricity. Elsewhere the water from springs and wells is at least hot enough to heat homes and greenhouses, and to supply energy for low-temperature chemical processes.

While many exceptions are recognized, including the use of heat pumps to increase the temperature of geothermally heated water, the minimum temperature required for a geothermal resource to become useful is 80°C. The temperature drops involved in producing, distributing, and using the hot water, make this about the lowest temperature that can be used for residential and commercial space heating. The new residential groundwater heating systems are a notable exception to this as they make use of groundwater temperatures as low as 52°F.

There are many types of geothermal energy systems, with three types being the major ones. The first type is the hydrothermal energy system. This system consists of high temperature water and/or steam, which are stored in porous and semipermeable reservoir rocks. The second type is the hot-igneous system. This system consists of magma chambers near the earth's surface, which are created by the buoyant rise of molten rock generated deep in the earth's crust. The third system is the conduction-dominated system. This system makes use of the heat that is transferred from great depth within the earth to its surface through thermal conduction. In order to reach useable temperatures, with this system, one would have to drill about 5-10 km deep. This last system is currently not economical to operate and therefore only the first two types will be discussed in this paper.

In general, and particularly considering the magnitude of the resource that it represents, the present worldwide usage of geothermal energy is in fact very small. The ideas and most of the technology required to correct this now exists. It appears quite possible that within the next 20 years, geothermal energy can be make broadly available at a cost in money, effort, and environmental deterioration that would be readily affordable. This paper will try to give an understanding of the theory, resources, and methods available in the present geothermal industry along with a summary of new developments which may contribute to the use of geothermal energy to its full potential.

HISTORY

The use of natural geothermal phenomena such as hot springs have been used for centuries for bathing purposes by the Etruscans, the Romans, Greeks, Japanese, and many others. These thermal waters were alleged to possess healing and prophylactic properties when applied externally, as in bathing or internally when taken orally. This was the birth of the balneology industry - the study of the therapeutic effects of hot springs.[3] The Maoris of New Zealand have long been using geothermal waters and fumaroles for everything from bathing to laundry and cooking. Another early application of natural thermal activity was the procurement of minerals from these "boiling springs". These springs were exploited for their sulfur, alum, boric acid, and vitriol.[1]

The first attempt to harness the energy found in these springs was made in 1897, by using natural steam to heat a boiler and produce pure steam for a reciprocating engine. On July 4, 1904, the first electric power was generated, in Italy, from geothermal steam under the direction of Prince Ginori Conti, when a small motor was operated by natural steam to drive a dynamo connected to some electric lamps.[2]

In 1912, the first turbine generator unit powered by underground steam was installed in Lardarello, Italy. The condensing turbine, driving an alternator was supplied with purified steam obtained from evaporators, since the high gas content of the natural steam made it difficult to maintain a vacuum in the condenser. By 1944, the installed electric-generating capacity of this first system had reached 127 mega-watts, but was destroyed in the later stages of World War II. In the 1920's, geothermal power investigations were also made in California, Japan, and Iceland and although no major developments came of these, the importance of geothermal energy had been recognized.[1]

TYPES OF SYSTEMS

As discussed in the introduction, there are basically three major types of geothermal systems, hydrothermal systems, hot-igneous systems, and conduction-dominated systems. The purpose of this section is to give a general background on the origin of this "energy" stored beneath the earth's surface.

The first major type of system is the hydrothermal system. This system can be subdivided into two parts, the hot water system and the steam system. This system operates in the following manner: In its slow circulation through permeable crustal rocks, water from rain or melting snow may encounter rock at relatively high temperatures and expanding as it is heated, rise buoyantly toward the surface. If it is prevented from reaching the surface by some barrier, an underground reservoir may form within which the water circulates convectively. This circulation extracts enough heat from the lower part of the reservoir to make up for the heat lost at the top and sides and eventually establishes an equilibrium. The temperature in this equilibrium can range from atmospheric temperature to 350°C. Hydrostatic pressure on this fluid is usually high enough to keep it from boiling even when superheated, and during its circulation the fluid becomes saturated with the minerals with which it comes in contact. Since the solubilities of minerals increase with temperature, hotter geothermal waters are generally higher in their contents of dissolved mineral matter and more troublesome with regard to corrosion and scaling when an attempt is made to recover and use them. Sometimes, the fluid pressure in a hydrothermal reservoir is not sufficient to prevent boiling, and then a pocket of steam forms in at least the upper part. During boiling, most of the dissolved minerals are left behind in the water, and it is commonly assumed that the lower part is occupied by a concentrated brine. Except for a variable content of such other gases as carbon dioxide and hydrogen sulfide, the steam formed is reasonably pure, and is an economical energy source for driving turbines and generating electricity. Existence of a large, bounded volume of rock within which temperatures are high enough and pressures low enough to permit boiling are rare, and natural steam reservoirs are therefore less common than hot-water reservoirs. Both of these systems are illustrated in Figures 1 and 2. Nevertheless, the largest geothermal power development in the world (at the Geysers, in California) uses steam from one of these reservoirs.[2]

The second system is the hot igneous system. This system consists of magma chambers near the earth's surface, which are created by the buoyant rise of molten rock generated deep in the earth's crust. A hot igneous system can be divided into two major resource groupings; hot, dry rock, where the magma is no longer molten, and volcanic, where the magma is still partly molten. In the latter case, because of great depth and very high temperatures, the heat is not recoverable with current technology. The hot, dry rocks, however, are located on the margins of the molten magma chamber. These rocks are favorable candidates for recovering heat energy. A system of hydraulic fractures can be created between spec-

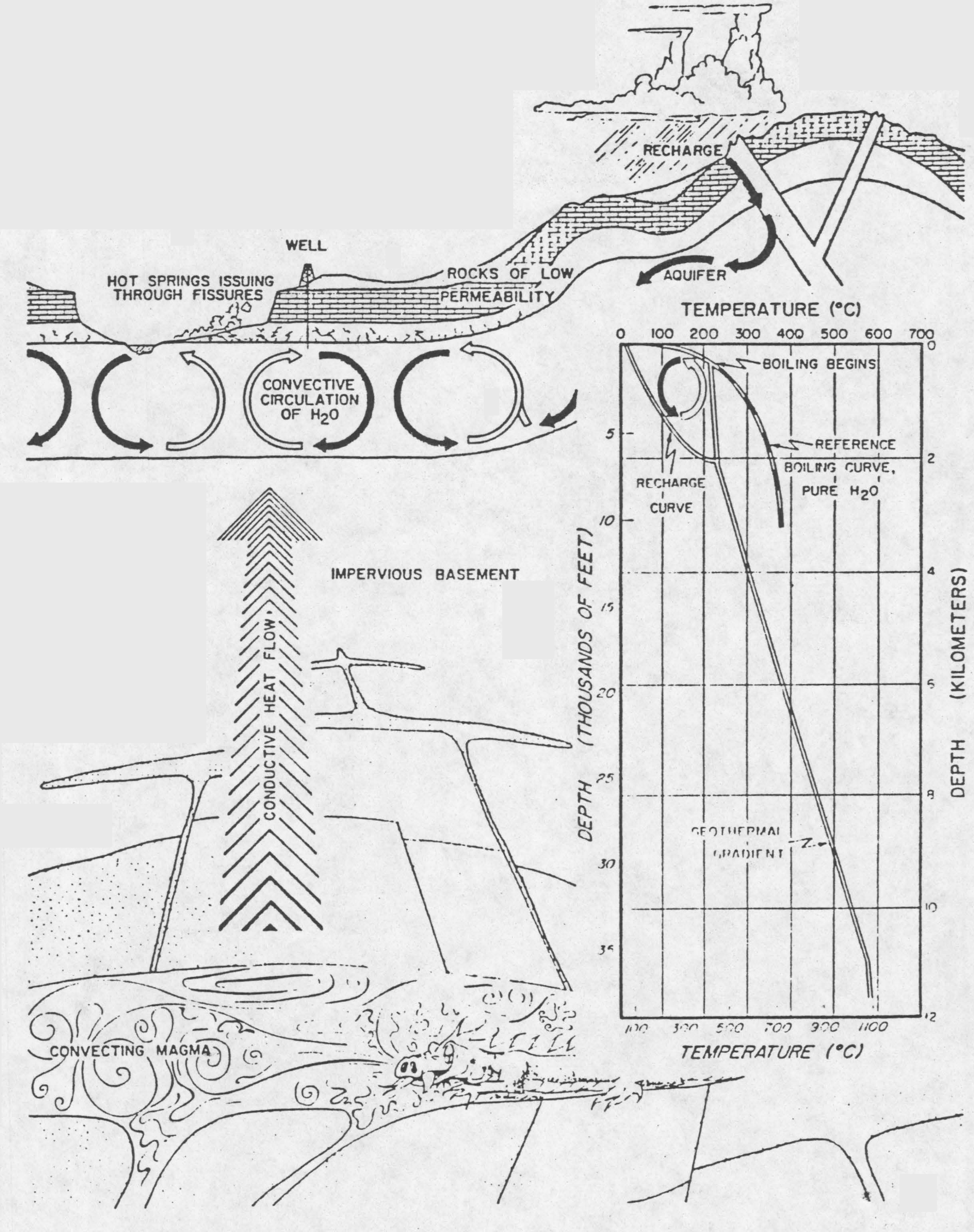


Figure 1 : Conceptual model of a hot water geothermal system.
(from Gupta, Geothermal Resources)

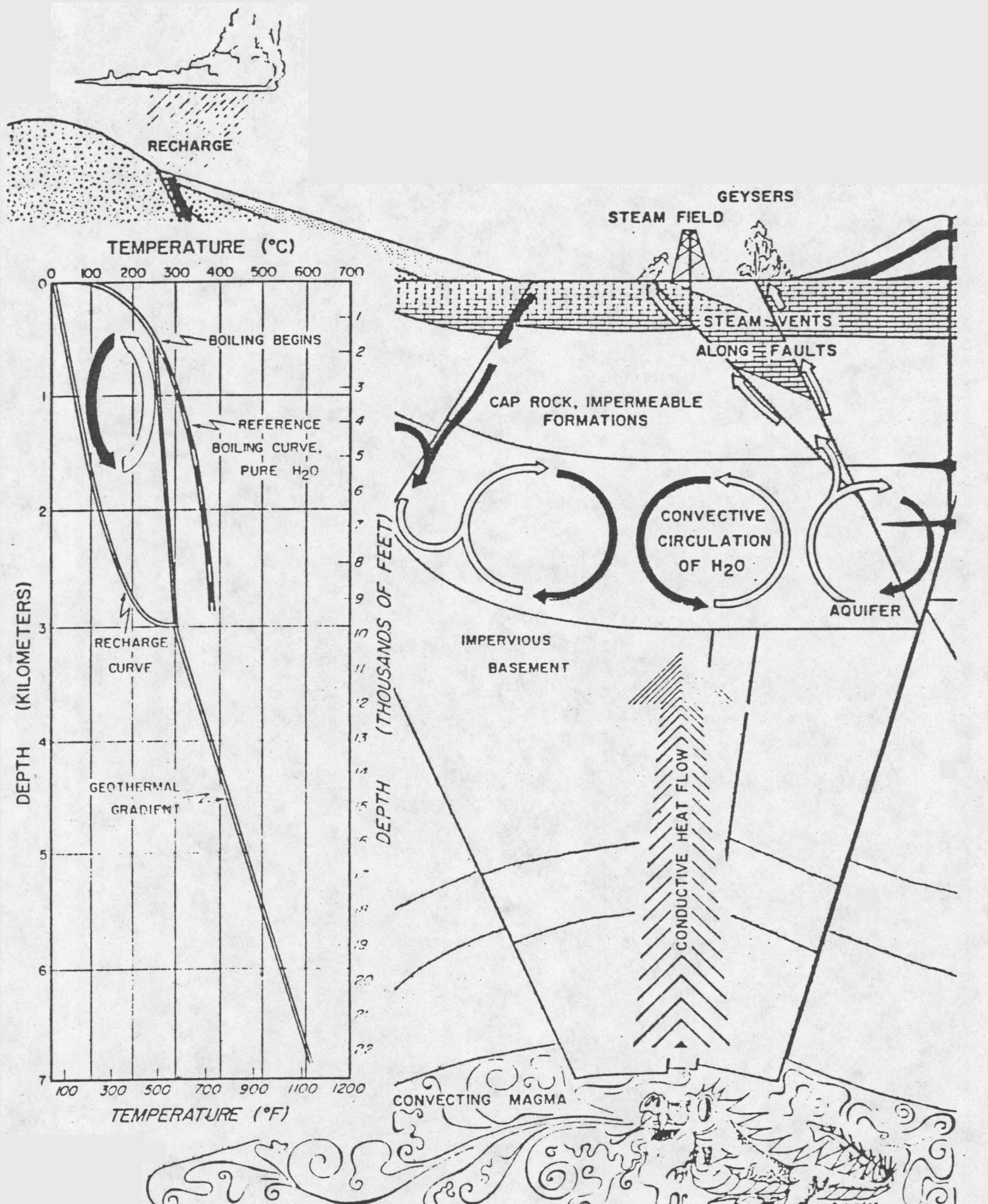


Figure 2 : Conceptual model of a steam geothermal system.
(from Gupta, Geothermal Resources)

ial, directionally-drilled wells in order to provide circulation loops in rocks having low to very low permeability values. In general, the economic extraction of energy from this resource lies in the future, although very aggressive research is currently being performed at Los Alamos, New Mexico. The hot rock system is pictured in Figure 3.[3]

EXPLORATION

The ultimate objective of any exploration program is to locate a resource that can be economically developed. Despite differences in the type of resource sought and hence, in the geologic setting, a certain exploration philosophy has been built up over the years. This philosophy is based on the concept that the prospector begins his search in a large area, narrowing down the area under consideration as more and more data become available until the resource is located. In the early stages of exploration, when areas to be investigated are large, rapid low-cost reconnaissance techniques are employed. As results accumulate and the search narrows, confidence increases and more expensive techniques can be utilized. In the case of geothermal exploration, this would continue until the most expensive technique, the "wildcat" well is used to test the prospect.[3]

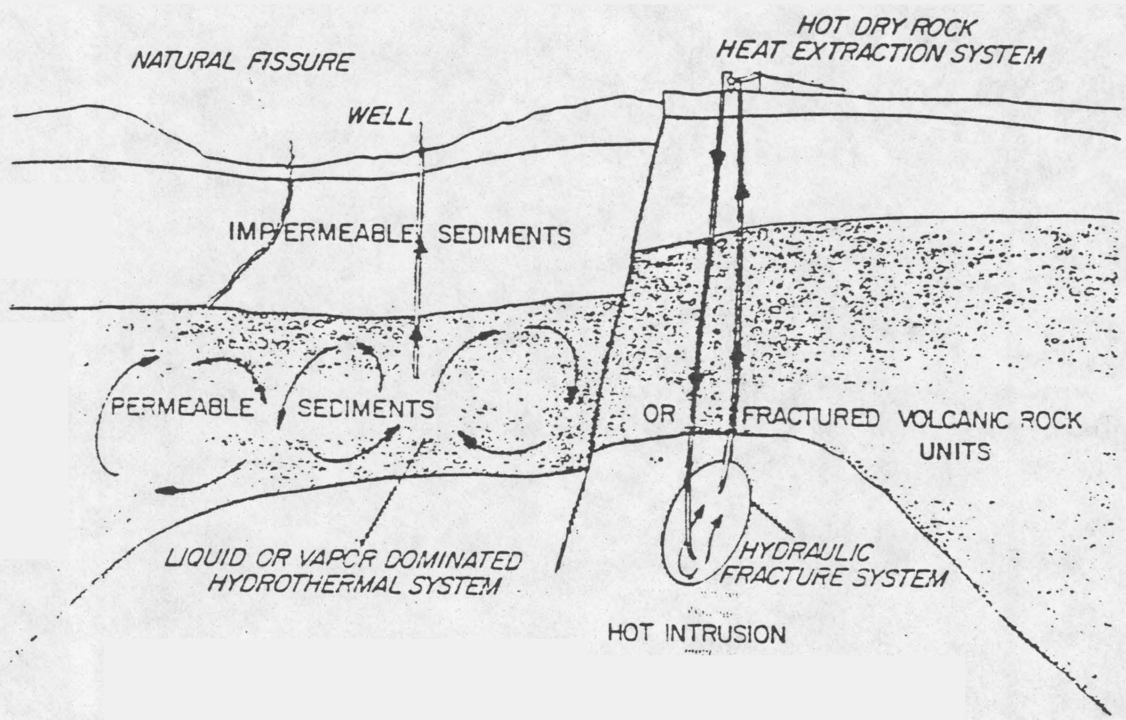


Figure 3 : Schematic diagram of a hot. dry rock geothermal system. shown adjacent to a hydrothermal reservoir.

(from Edwards and Chilingar, Handbook of Geothermal Energy)

The objective of geothermal exploration is obviously to locate a geothermal system from which energy can be economically extracted. Because high geothermal gradients are a prerequisite for any type of geothermal system, the initial exploration effort should concentrate on defining such anomalous areas. When an area of high geothermal gradient or heat flow is identified, emphasis shifts to an evaluation of the permeability and hydrology of the area. There are many techniques which are used in the exploration of geothermal areas, and these will be discussed in the sections to follow.[3]

Seeps and Fossil Seeps

The first technique is that of seeps and fossil seeps. Leakage of fluids through the impermeable capping often occurs in natural geothermal systems. These leaks or seeps, which may produce such features as fumaroles, hot springs, geysers, and mud volcanoes, are the most direct and obvious indicators of the presence of a geothermal system. These seeps commonly result from seismic activity that fractures the impermeable caprock and permits fluid escape to the surface or into near-surface groundwater. Active volcanism or the presence of very young extrusive igneous rocks are also direct indicators of high geothermal gradient, and thus are closely related to seeps in their applicability to geothermal exploration. Because most of the world's commercial geothermal systems are closely associated with young volcanic rocks, exploration has been concentrated in the near vicinity of these rocks.[4]

Geological Techniques

The next group of exploration techniques are the geological techniques. The geological techniques consist of literature search, mapping, petrology, and fracture studies. The literature search includes searching the professional journals, publications of federal and state agencies, university theses and dissertations, and in the U.S., reports from national laboratories. The results of this search should be compiled into a preliminary model of the area. A decision can then be made as to whether further development of this area is warranted. A literature search is an inexpensive exploration technique, and the dividends from a careful search can be great. The next geological technique is the mapping of the area. Careful geologic mapping is the foundation on which any exploration program is built and all other data must be interpreted in terms of the observed geology. This mapping should emphasize young igneous rocks that could act as heat sources, potential reservoir rocks, distribution and nature of fractures and faults, and the distribution and nature of hydro-thermal alteration. In this mapping, field work should be supplemented where possible by satellite imagery and aerial photography, including low sun-angle photography. The detail or scale of mapping should reflect the stage of exploration. In the reconnaissance stage, a scale of 1:125,000 to 1:62,500 is appropriate and in the later stages a scale of between 1:24,000 and 1:5,000 is conventionally used.[3]

The use of petrology is also useful in exploration. Petrologic investigations of igneous rocks, the potential reservoir rocks, and impermeable capping can aid in the definition of the size of the anomaly and help predict fluid characteristics, which eventually will affect development and utilization. These investigations should include the determination of modal composition, textural examinations, and fracture and alteration studies. These petrologic investigations can provide clues about the igneous sources such as: differentiation of the magma, depths of emplacement, duration of the igneous event, and the magnitude of the thermal effects on the wall rocks.

The last geological technique is that of fracture studies. Knowledge of the frequency, size, and orientation of fractures and faults is important in the exploration for and assessment of any type of geothermal reservoir. In most natural fluid-dominated systems, fracture-controlled permeability, is the most important type of permeability that controls production from the wells. Geopressured systems are typically bounded by large fractures or faults which ultimately determine the size of the reservoir. In the case of hot dry rocks, it is the presence of fractures and the nature of fracture-filling minerals that determines if this energy extraction method can be applied. For these reasons it is imperative, as part of any geothermal exploration program, to characterize the nature of fractures present within the area.[4]

Geochemical Techniques

The use of geochemical methods in the exploration for geothermal resources consist of four methods. These are the use of chemical geothermometers, trace element investigations, geochronology, and hydrologic investigations.

Chemical geothermometers play a vital role by helping to predict reservoir temperatures prior to drilling. The most widely applicable of these are the silicon and cation geothermometers, which have been used for both reconnaissance and detailed exploration. By utilizing these results, companies can save vast amounts of money by not drilling in "cool" reservoirs, after reviewing the results.

Another method is the use of trace element investigations. Trace element concentrations in rocks, soils, water, and plants, and can be used in locating geothermal resources having igneous heat sources, because certain elements are genetically related to volcanic rocks. Because of its high mobility both in the vapor phase and in aqueous solutions, mercury is one of the most promising indicators for geothermal exploration. The gases helium and radon have also been used for geothermal exploration and assessment, but the results are much more tenuous and the methods are not currently in wide use. When compared to other methods of exploration, trace element analysis is used very infrequently.[5]

The third method is the use of geochronology. Because many geothermal systems are closely associated with young igneous rocks, geochronology can be a valuable tool in the exploration of geothermal resources. In the age range of interest in geothermal exploration the K-Ar method is by far the most useful for dating igneous rocks. In rare cases, where the rocks are extremely young and organic material can be related to the igneous activity, the ^{12}C method can be used: The use of geochronology as an exploration tool is a valuable part, but must be used in conjunction with the other methods in order to effectively aid in the location of resources.[5]

The final geochemical method is the use of hydrologic investigations. A thorough knowledge of the hydrology of an area is necessary for the effective evaluation of the resources in an area. In fluid-dominated and geopressured systems, naturally-occurring aqueous fluids are the agent by which energy is transported from the reservoir to the earth's surface. This allows one to see the importance of hydrology in understanding geothermal systems. In hot dry rock systems, hydrologic methods are significant in defining the permeability of the system, predicting fluid loss, and in evaluating other exploration techniques such as heat flow measurements. The objectives of a hydrologic investigation are therefore to determine the source of the fluids, areas of recharge, infiltration rate, location, depth, pressure, composition, and temperature of aquifers. This system determines this data by the use of oxygen and hydrogen isotopic and tritium analysis of the water and streams.[5]

Geophysical Techniques

The use of geophysical exploration techniques have proven useful in locating the heat sources of geothermal systems and characterizing the permeability of the potential reservoir. The geophysical techniques currently used consist of gravity measurements, aeromagnetic measurements, and heat flow measurements. Gravity mapping has proven useful in several aspects of geothermal exploration. Of primary importance is the utility of this method in locating and defining the extent of heat sources. Because of the close association between young silicic igneous rocks and fluid-dominated geothermal systems and because of the low density of these silicic plutons, the use of gravity measurements to locate these areas can be seen to be very effective. If magma is still present in the system, density differences are likely to be even greater, increasing the probability that they can be found through gravimetric measurements.[5]

Aeromagnetic surveying, although not as widely used as some of the geoelectro-magnetic techniques, is becoming increasingly more prevalent for use in reconnaissance. This method is useful for regional structural analysis and when combined with Curie point depth determinations, for defining large regions of the crust having elevated temperatures. This latter method is based on the fact that magnetic minerals in rocks lose their magnetism at some specific temperature referred to as the Curie temperature. Conventional aeromagnetic data can be used to calculate the depth to the Curie temperature, thus providing at least a crude estimate of the average geothermal gradient.

The use of heat flow in exploration is a very important tool. In theory, heat flow is the most unambiguous indicator of the presence of a geothermal system, because the property sought is being directly measured, but this method has two distinct disadvantages. First, the method is expensive to apply and, second, because of local hydrologic effects, it is often difficult to interpret the results.[4] Another disadvantage with the use of the heat flow method involves distinguishing between conductive and convective contributions to the heat flow. Local near-surface hydrologic disturbances can either mask high conductive heat flow at depth or falsely indicate high conductive heat flow. This method is used to construct maps like the one in Figure 4.[7]

Geoelectromagnetic Techniques

At present, the major emphasis in geothermal exploration seems to be in the application of geoelectromagnetic methods such as magnetotellurics (MT), audiofrequency magnetotellurics (AMT), and deep electrical resistivity. There are also other techniques used. These techniques can be broadly separated into those utilizing natural fields and those where a controlled source is used.

Natural Field Methods

The first method is the self-potential method. This method, widely used in mineral exploration, is based on measurements of variations in the natural dc voltage which result from the interaction of ground water with conductive bodies, such as sulfide or graphite deposits; from high geothermal fluids. Although the SP method has successfully located many areas of geothermal activity, the method has several disadvantages: the causes of the anomalies are poorly understood, topographic effects may be significant, and telluric currents (or naturally occurring currents) may cause errors. High noise levels may also influence data received by this method.

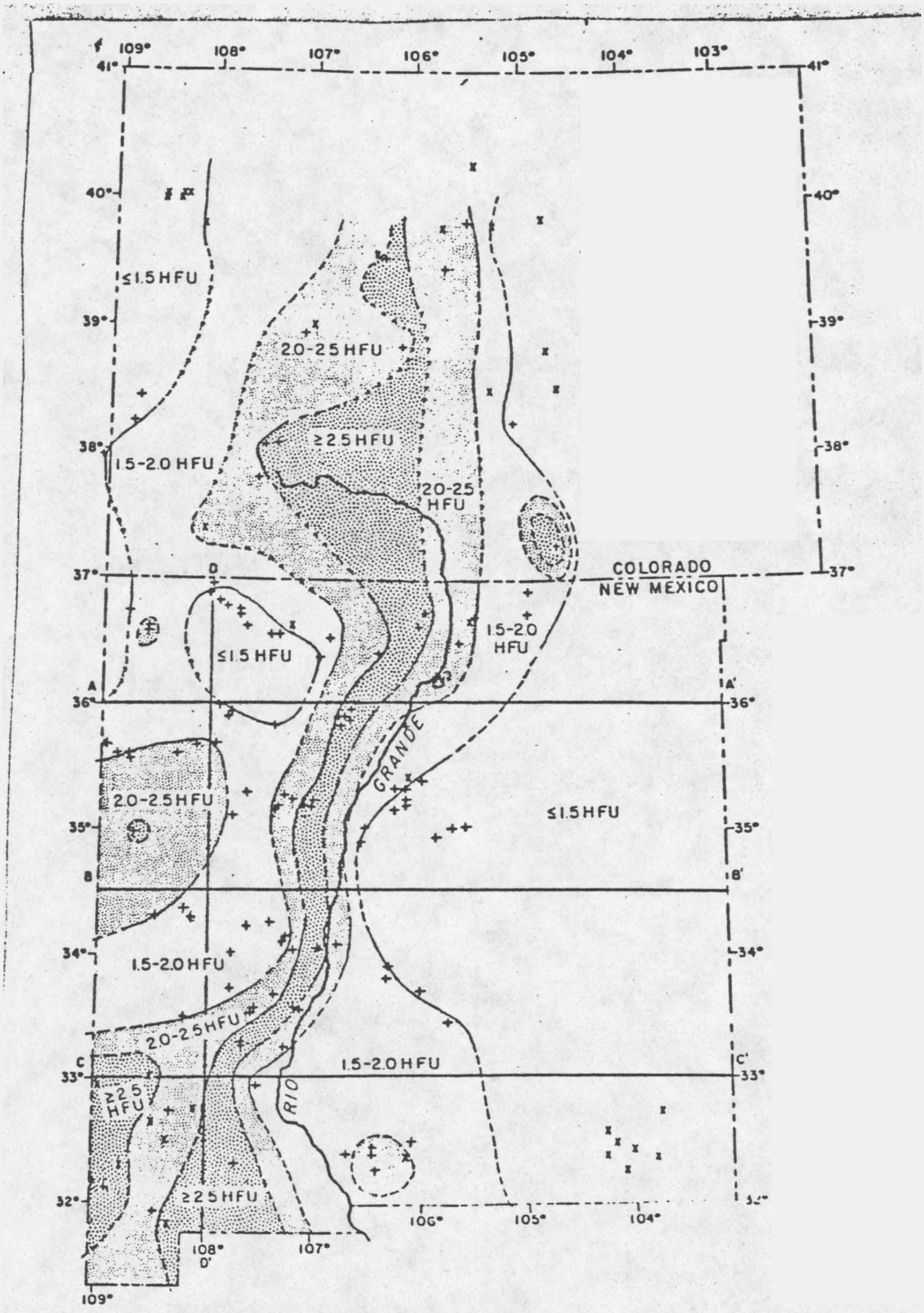


Figure 4 : Terrestrial heat-flow contour map of New Mexico and southern Colorado. Contour interval = 0.5 HFU.

(from Edwards and Chilingar, <u>Handbook of Geothermal Energy</u>)

Telluric Methods

Two different telluric methods have been used in geothermal exploration, vector-tellurics and telluric profiling. Both methods rely on the measurement of natural electric fields at frequencies of less than 20 Hz. Although both techniques utilize relatively simple instrumentation, the costs of data processing are high and neither method is in wide use at the present time. Because of its sensitivity to lateral changes in resistivity, the telluric profiling method is most useful, particularly, when the strikes of contacts are known and survey lines can be oriented perpendicular to the strike.[8]

Magnetotelluric Methods

These methods cover the natural electrical and magnetic fields in the range from dc to about 20,000 Hz. The MT method, which utilizes frequencies up to about 100 Hz, is useful in defining deeper structures and conductors; whereas the AMT method, or audiofrequency magnetotelluric method, utilizing the higher frequencies, is limited to relatively shallow penetration associated with the low frequency MT signals make the MT method useful for defining deep electrical conductors in the crust, which may ultimately control the location of geothermal fields. The MT and AMT methods offer considerable promise in both reconnaissance and detailed scale exploration. They both, however, are adversely affected by cultural features such as powerlines, pipe lines, and fences. Despite these disadvantages, the methods are being increasingly used in geothermal exploration.[6]

Controlled Source Methods

Resistivity Surveying

Several methods for evaluating vertical and lateral variations in electrical resistivity are in common use in geothermal exploration. These include the bipole-dipole, dipole-dipole, Schlumberger profiling, and Schlumberger sounding methods. All of these methods are based on injecting a dc current into the earth by means of a current electrode pair and measuring the resulting dc field with a second electrode pair. Electrode arrays and instrumentation for measuring the voltage between receiving electrodes vary with the method, but all methods produce a map similar to the one pictured in Figure 5. In the bipole-dipole method, a long current electrode pair (bipole), up to several kilometers in length, is used to inject the dc current while short receiving electrodes (dipoles) are moved about over the ground surface to produce either resistivity maps or profiles. The current injected may be as large as a few hundred amperes with potentials of several hundred volts. The dipole-dipole method employs transmitter and receiver electrode pairs of equal length. Separations between the transmitter and receiver dipoles are integer multiples of this dipole length. In the Schlumberger

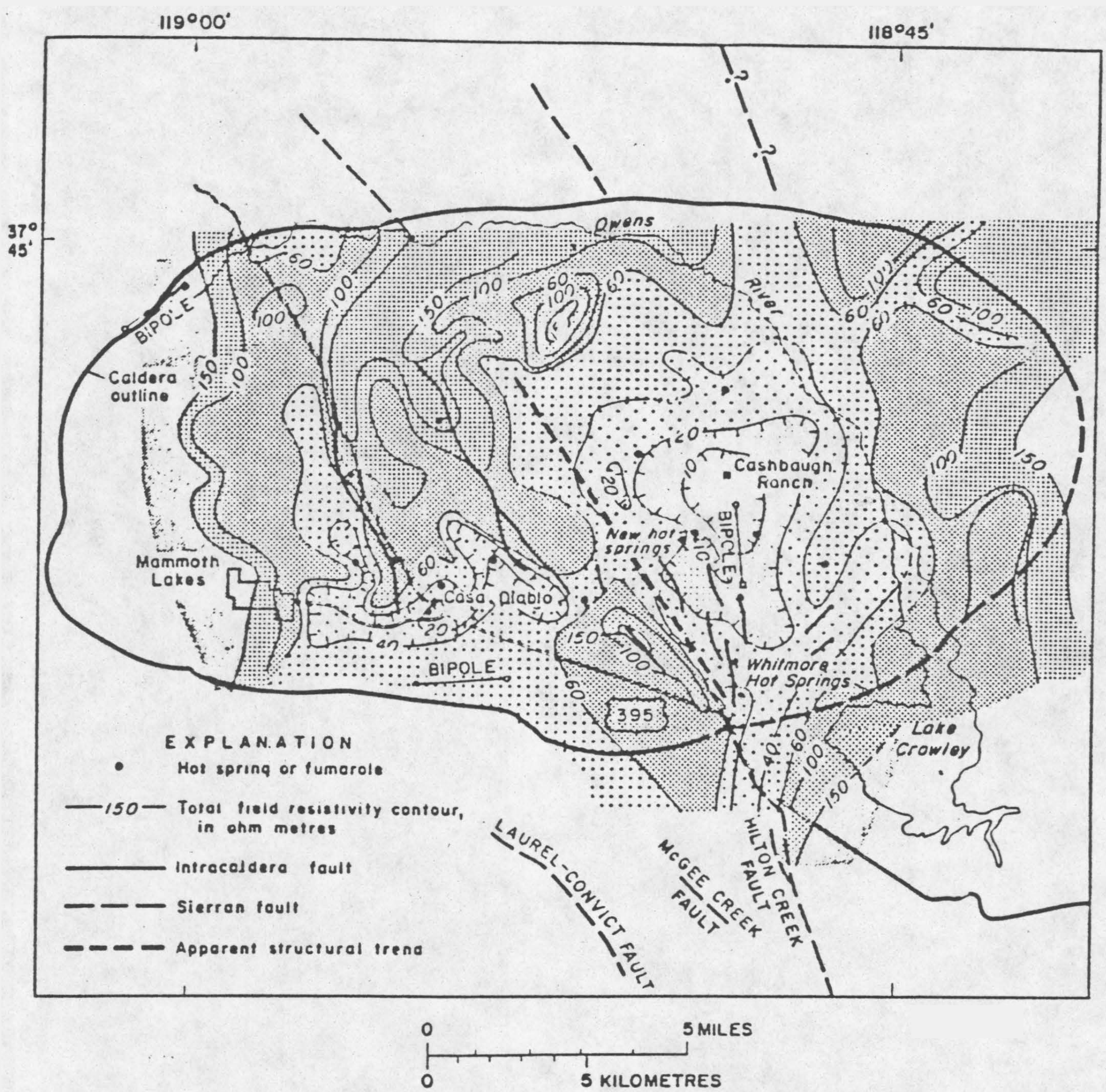


Figure 5 : Composite total field resistivity map of Long Valley Caldera.

(from Edwards and Chilingar, Handbook of Geothermal Energy)

array, the four electrodes are placed in a line with the receiver pair located at the center of the transmitter pair. During the measurements, the separation of the transmitter dipole is increased to penetrate to successively greater depths. The Schlumberger array can be used for either vertical soundings at a given point or for construction of electrical profiles by correlating between individual soundings.

Time-Domain Electromagnetic Surveying (TDEM).

This is a relatively new technique, which appears to offer great potential in geothermal exploration. In this method, a short grounded-wire source is used to transmit a current step of many frequencies. A vertical-axis loop receiver or cryogenic magnetometer is then used to measure the time rate of change of the induced magnetic flux. The signals obtained are interpreted to yield the variation of the apparent resistivity with depth. This data results in a map like the one in Figure 6.[6]

Seismic Methods

A variety of seismic methods, active and passive, have been used in geothermal exploration. The active methods include both refraction and reflection profiling to determine geologic structure around geothermal reservoirs. The passive teleseismic technique has also been used in structural investigations. These techniques employ the use of a device to supply the seismic disturbance (shot) and measuring devices

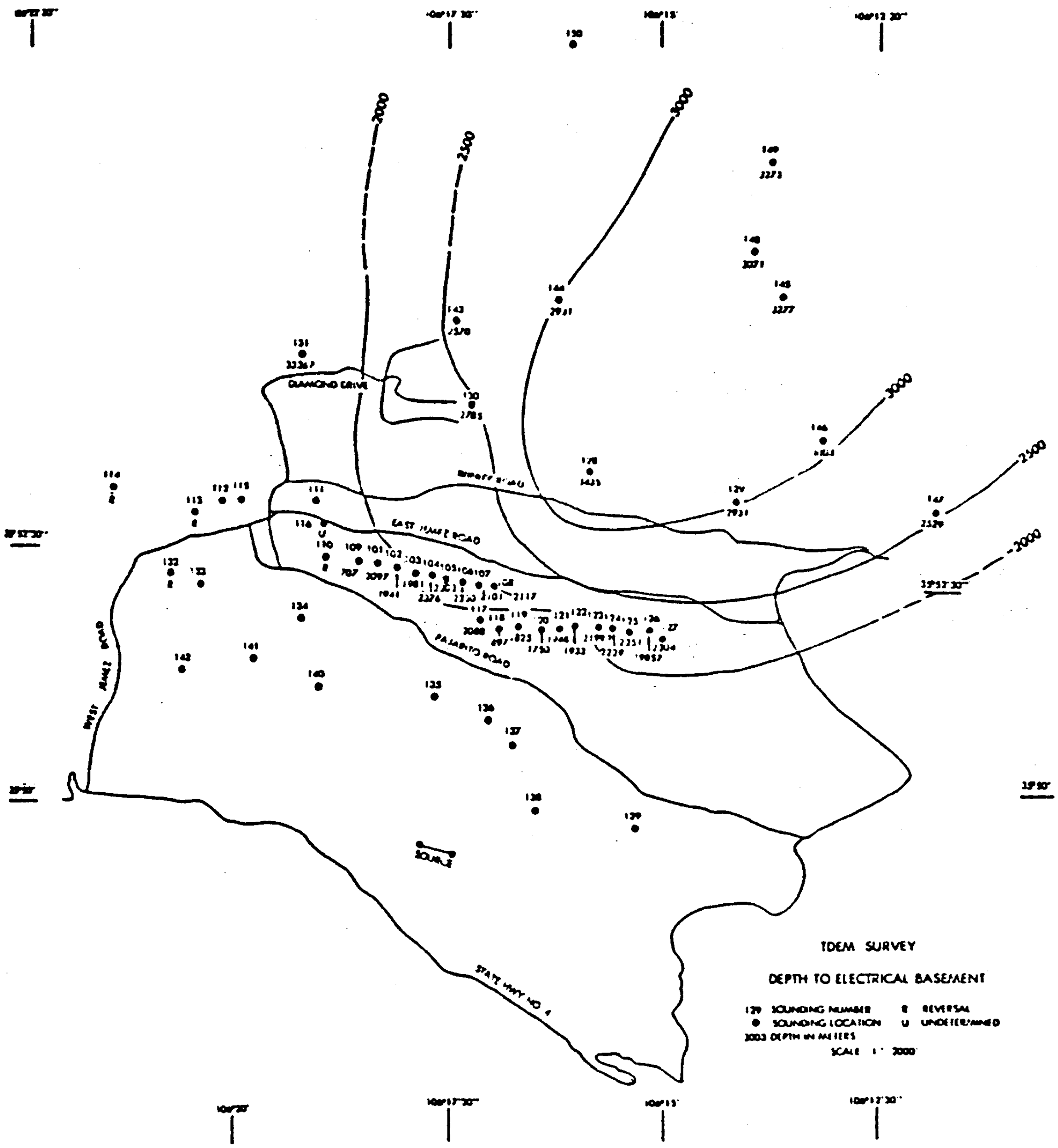


Figure 6 : TDEM survey of the east side ~~of~~ the Valles Caldera, New Mexico.

(from Edwards and Chilingar, Handbook of Geothermal Energy)

to record the reflections and refractions. This data is used to indicate the presence or absence of underground geologic structures.

These are all the methods currently used in the search for geothermal energy. Progress is constantly being made in this area, and the methods are being revised to make them more accurate and less expensive.[6]

UTILIZATION

Drilling Technology

Drilling for geothermal energy is quite similar to rotary drilling for oil and gas. The main differences are due to the high temperatures associated with geothermal wells which affect the circulation system and the cementing procedures as well as the design of the drill string and casing. In conventional rotary drilling for geothermal energy, a rig similar to that used in oil drilling is used. To facilitate mobility, all the components would preferably be trailer mounted. Mud is usually used as the drilling fluid. Clay-based muds, such as bentonite, are the most commonly used in geothermal drilling at low temperatures, while at higher temperatures a chrome-lignite mud is used. The temperature of the muds is often reduced by installing cooling towers at the surface. The bits used are those with hardened steel teeth or tungsten-carbide inserts, and the mortality rate of these bits are high at the higher temperatures encountered underground. To obtain a sustained flow of steam or fluid from the underground reservoirs, the well must be cased. This casing must be capable of withstanding wear, corrosion and attrition due to friction and vibration. To prevent losses of drilling mud, the well must also be cemented at the horizons where these losses can occur. The actual drilling process is a fairly simple and straightforward procedure.

The safety measures to be observed while drilling for geothermal energy, are much the same as for conventional petroleum wells and are as follows: gas detectors and masks should be readily available because of the poisonous gases that can be emitted from wells, an adequate water supply should be on hand for the purpose of suppressing blowouts and of course for fires, an escape cable and seat on the derrick in the event that hot water and steam come gushing out of the well prematurely.[7]

USES OF GEOTHERMAL ENERGY

Now that the energy has been recovered, it needs to be developed. There are many uses of geothermal energy. Among the uses are electrical power production, animal husbandry, and space heating and cooling.

Electric Power Production

The largest practical application, approximately 33 percent, of geothermal energy is for the generation of electrical power. Since 1950, the technology has progressed rapidly,

with more than 1500 Mw worldwide on line in 1981.[1] On a nationwide scale, experts believe that there is geologic potential to produce enough geothermal energy to supply 20,000 Mw of generating capacity by the year 2000, (See Figure 7), equivalent to 700,000 barrels of oil a day or 8.7 percent of USA crude oil production. Presently operating electrical generating systems listed in Figure 8 fall into the following categories as regards the form of geothermal fluid used:
1) dry steam directly from the reservoir, after minor cleanup used as a working fluid for a low pressure turbine (steam).
2) flashed steam, hot water flashed by dropping its pressure to form steam and water that are separated, the water is rejected and the steam is used to drive a low pressure steam turbine 3) binary cycle, heat from hot water transferred to a secondary working fluid such as freon or isobutane which is vaporized and used to drive a turbine.[8]

Agricultural and Animal Husbandry Industry

The use of geothermal energy to heat greenhouses has been practiced for quite a while. The most famous of these are found in Iceland where tomatoes and bananas are harvested year round in geothermally heated greenhouses. The popularity of geothermal fluids as the source of heat for greenhouses is owed to the fossil fuel industry and the high cost of heating oil. The geothermal fluids are circulated into radiators which are used to directly heat the greenhouse.

Figure 7

Geothermal Electric Generating and Nonelectric Capacities

(from Edwards and Chilingar, Handbook of Geothermal Energy)

Country	Installed (1981) Electric MW(e)	Installed (1981) Nonelectric* MW(t)	Future Projections by 2000 Electric MW(e)	Future Projections by 2000 Nonelectric* MW(t)
United States	930	17	~2,000	~3,400
Philippines	500	4.9	765	?
Italy	420	24	800	38
New Zealand	203	196	400	380
Japan	165	2,900	~2,000	3,100
Mexico	150	—	150	680
El Salvador	95	—	180	—
Iceland	32	410	150	570
USSR	5	4,860	?	?
China (Taiwan)	1.9	0.6	?	5
Turkey	0.5	0.2	400	?
Nicaragua	—	—	150	?
Costa Rica	—	—	100	—
Guatemala	—	—	100	—
Honduras	—	—	100	—
Panama	—	—	60	—
Argentina	—	—	20	—
Portugal	—	—	30	—
Spain	—	—	25	10
Kenya	—	—	30	—
Indonesia	—	—	30-100	—
Thailand	—	—	~10	—
Canada	—	—	—	10
England	—	—	—	~2
France	—	24	—	490
Hungary	—	1,050	—	?
Czechoslovakia	—	93	—	?
Yugoslavia	—	4.9	—	58
Total	2,502 MW(e)	9,585 MW(t)		

Figure 8 : Geothermal Power Plants (from Bowen, Geothermal Resources)

Plants	Mw Capacity	Initial Operation
Dry Steam		
Italy		
Larderello	380	1904
Monte Amiata	26	1967
USA		
The Geysers, CA	502	1960
Japan		
Matsukawa	22	1966
Onikobe	25	1975
Flashed Steam		
New Zealand		
Wairakei	192	1958
Kawerau	10	1969
Japan		
Otake	23	1967
Hatchabaru	50	1976
Katsukonda	50	1977
Mexico		
Pathé	4	1958
Cerro Prieto	70(?)	1973
Iceland		
Kafla	70	1977
Philippines		
Tiwi	10	1969
USSR		
Pauzhetsk	6	1967
El Salvador		
Ahuachapan	30	1975
Binary cycle		
USSR		
Paratunka	1	1967
USA		
Imperial Valley, CA	10 50	Late 1970s to 1980

In some instances the fluids are used directly to sterilize the soil as in the growing of mushrooms.

These same fluids find wide application in the animal husbandry industry. In Hungary, they heat cattle stalls, milking rooms, pigsties, and chicken houses; in Japan, they aid in hatching eggs and raising poultry; and in New Zealand, they help to biodegrade the wastes from pigsties which decomposes more rapidly at higher temperatures. Some other uses are the washing and drying of wool, production of dried milk, casein, and sucrose, and crop drying.

Space Heating and Cooling

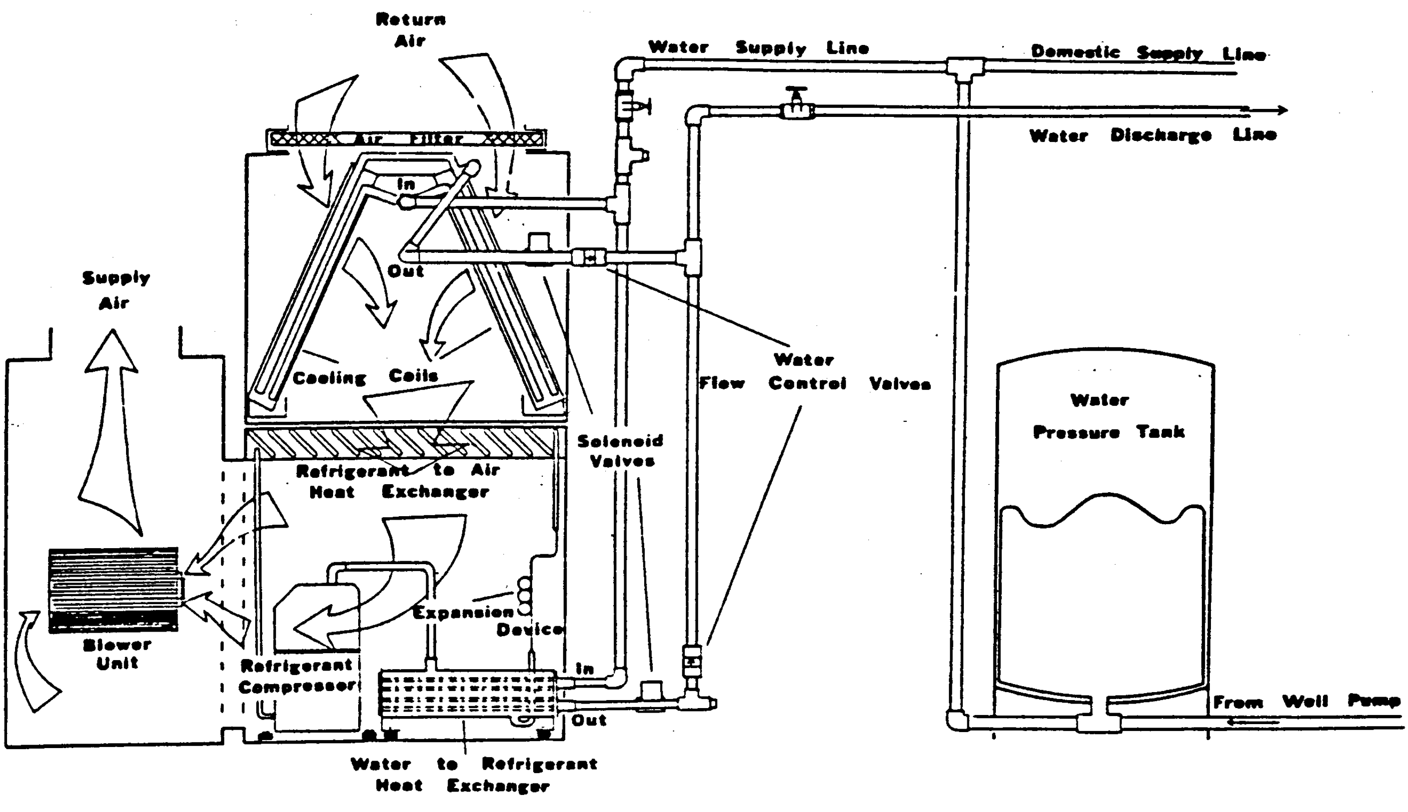
The last big use of geothermal energy is that of space heating and cooling. Iceland at present makes use of this energy source, but other countries including the U.S. are beginning to realize the importance of this fuel source. The general heating system that is now used operate something like this: the groundwater is circulated through tubes surrounded by cold refrigerant, this refrigerant absorbs heat from the water, this refrigerant now much warmer enters a compressor where it is pressurized, which raises its temperature considerably, the now hot refrigerant is circulated into an air heat exchanger, where the heat is transferred to the air which is then circulated throughout the building, the refrigerant then returns to begin the cycle over again. The general cooling system operates something like this: cold groundwater is circulated through the building. These two systems are relatively similar in appearance and an example is shown in Figure 9.[7]

CONCLUSIONS

The future of geothermal energy may be seen as a series of dependencies. The rates at which thermal and electrical power from geothermal resources are brought on line. The encouragement and support given development of a strong geothermal energy industry in the United States in turn depend on the degree to which governmental bodies and the public understand the position and promise of geothermal energy relative to the other "alternative" sources now being developed or advocated. These advantages are sufficiently recognized so that a growing geothermal industry already exists in the United States, although at present its growth is greatly retarded by primarily institutional obstacles that it must overcome. With the minimal encouragement and support it is now being given, its growth rate will continue to be low until about 1990 when, its merits having been demonstrated to the satisfaction of the more conservative elements of the utilities and financial communities, a rapid growth of the industry can be expected to occur spontaneously.[2] By appropriate government actions, the time at which this rapid growth begins can be significantly advanced.

Figure 9 : Space Heating and Cooling System

(from bulletin of Grace Geothermal Inc.)



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